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STUDY ON SLUDGE TREATMENT
(2nd Report)

H. Kawahara, M. Tsuchida
Y. Koido, I. Endo*, M. Sago**

Introduction

The first report[1] by the authors dealt with a consideration of the possibility of solidifying sludge from sewage and dredged mud. It also took into account the question of cost and, with the required compression strength as a factor, the exact composition necessary in developing a reliable hardening method. Since that report did not elucidate the properties of the sludge, particularly the effect that organic substances in the sludge have on strength, and also left untouched the problem of substances leaching out of the solidified material, these matters will be dealt with in this report.

1. Solidifying Sludge – Relationship Between Strength and the Amount of Organic Substances in the Sludge

(1) Samples

Test samples included sewage sludge from the Shibaura Sewage Treatment Plant (96% water and 60% organic substances), and digested sludge (95% water and 47% organic substances). Quick Portland cement was used.

(2) Test Method

Composition C/S (C = weight of cement and S = wet weight drain sludge) was varied thus: 0.2, 0.3, 0.4, 0.6, 0.8, and 1.0. A cement mixer was used for mixing and kneading the components together. The sludge sample was put in first, followed by the cement, and mixed for one minute at low speed, after which they were mixed at high speed for two minutes. The liquid mix, which has a high rate of flow was poured in one layer into the triple mold and the sides of the molds knocked with a mallet to pack the mix down and it was then left to harden.

(3) Results and Discussion

1) Solidification of raw sludge

The solidification of raw drain sludge is considerably affected by the sludge-cement quantity ratio, the nature of the sludge (especially the amount of organic substances it contains) and the amount of

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water in the sludge. These relationships were studied.

Figure 1 shows the tested relationship between σ_{28} (hardness 28 days after mixing) and C/S when sludge containing 96% water and the given amount of organic substances was used.

Figure 2 shows the relationship between σ_{28} and the amount of organic substances on the one hand and the various C/S values.

These results show that in solidifying raw sludge with cement, when the C/S ratio is over 0.6, the effect of the amount of cement on σ_{28} is great but the effect of the organic substances is scarcely observable. When the C/S ratio is down in the 0.2–0.6 range, the effect of the amount of organic substances in the sludge on σ_{28} increases considerably. It was also found that the minimum amount of cement necessary to bring about hardening is C/S = 0.2.

If, from the relationship between σ_{28} and C/S in **Figure 1**, C/S = 0.6 be taken as the limit, the following expressions are obtained:

When C/S = 0.2 – 0.6

organic substances contained in the sludge		
20 – 30%	$\sigma_{28} = -16.6 + 93\ C/S$	(1)
40	$\sigma_{28} = -11 + 65\ C/S$	(2)
45 – 50	$\sigma_{28} = -7.0 + 45\ C/S$	(3)
55 – 60	$\sigma_{28} = -3.4 + 27\ C/S$	(4)

Then, when expression 1 and 2 and also 3 and 4 are combined,

20 – 45	$\sigma_{28} = -11 + 65\ C/S$	(1')
and 45 – 60	$\sigma_{28} = -7.0 + 45\ C/S$	(3')

are obtained. Again,

When C/S = 0.6 – 1.0,

and organic substances contained in the sludge are

20 – 60%	$\sigma_{28} = -a + 180\ C/S$	(5)
	(a = 86 – 103)	

From **Figure 3**, the relationship to water content (%) is as follows:

(Water content (%) = $\frac{Ww}{Ww + Wd} \times 100$, where Wd is the weight of dried sludge and Ww = weight of wet sludge – weight of dried sludge. This differs from the water content ratio (Ww/Wd).)[2)]

Figure 1 Relationship between Organic Content and δ_{28} for Raw Sludge (Water Content 96%)

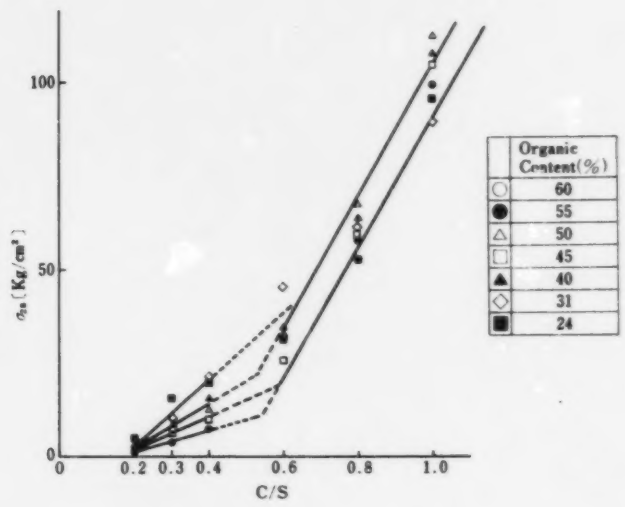


Figure 2 Relationship between Organic Content and δ_{28} for Raw Sludge (Water Content 96%)

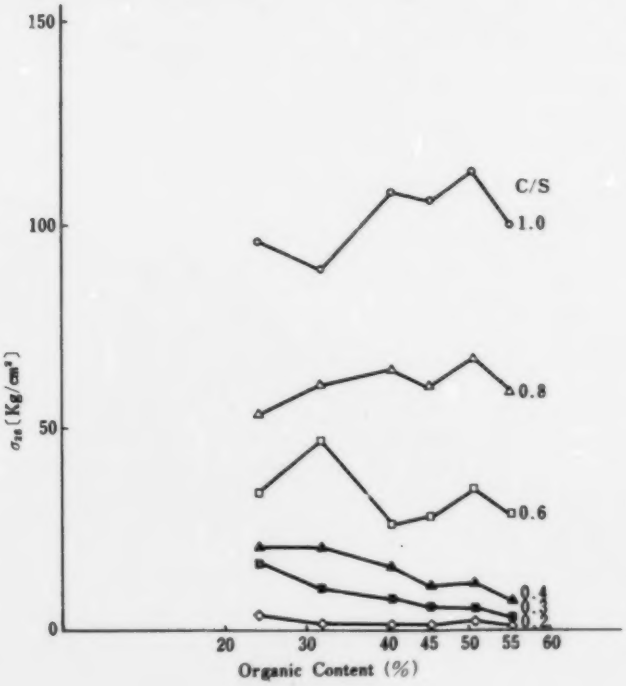


Figure 3 **Relationship between δ_{28} and Water Content for Raw Sludge (Organic Content 60%)**

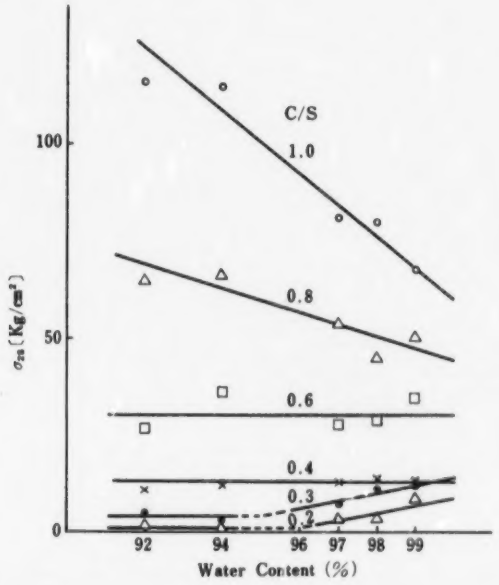
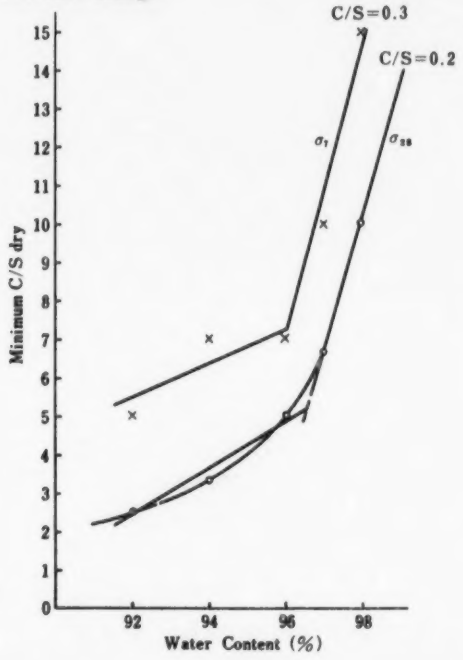


Figure 4 **Relationship between minimum C/S and Water Content for Raw Sludge**



C/S, provided W is a water content of (92 – 99%)

1.0	$\sigma_{28} = 125 - 8W$	(6)
0.8	$\sigma_{28} = 70 - 3.3W$	(7)
0.6	$\sigma_{28} = 30$	(8)
0.4	$\sigma_{28} = 13$	(9)
0.3	$\sigma_{28} = 4$ (92 – 96%)	
	$= -167 + 1.8W$ (92 – 99%)	(10)
0.2	$\sigma_{28} = 1$	
	$= -162 + 1.8W$ (92 – 96%)	(11)
	(96 – 99%)	

Figure 4 shows the relationship between σ_7, σ_{28} and water content. The saving of cement is considerable if water content is not reduced to below 96%. However, if the amount of solids in drain sludge is over 8%, mixing becomes difficult. This means that where sludge has a water content of 92–96% the minimum cement requirement is 5–7.5 kg per 1 kg of dried sludge. It has been found, experimentally, that solidification of sludge takes place when C/S = 0.2 and water content is 92–99%. In this case the minimum amount of cement required is 2.5–5 kg per 1 kg of dried sludge.

Table 1 lists the number of days taken for the sludge-cement mix to harden after mixing and then curing in both fresh water and sea water. A greater length of time was required when cured in sea water and where the water content of the sludge was constant, and in all cases curing in fresh water resulted in greater hardness. It would seem that this is because when the mix is cured in sea water the cement paste condenses and settles and there is a more marked increase in volume than when curing is carried out in fresh water.

2) Solidification of digested sludge

Figures 5 and **6** show the relationship between σ_7 and the amount of organic substances in digested sludge. These show that σ_7 is scarcely affected at all by the amount of organic substances but is determined by the C/S ratio.

Figures 7 and **8** show the relationship between σ_{28}, C/S and the amount of organic substances contained in the sludge. Then, in finding the relationship between C/S and σ_{28} from **Figure 9**. C/S = 0.4 is taken as the limit and the following relationships found:

C/S		
0.2 – 0.4	$\sigma_{28} = -a + 35C/S$ $(a = 3 - 6)$	(12)
0.6 – 1.0	$\sigma_{28} = -b + 106C/S$ $(b = 26 - 40)$	(13)

Table 1 Days Required for Curing of Sludge-Cement Blocks

Curing water	C/S	Water content (%) 92	94	96	97	98	99
Sea Water	1.0	3	4	3	1	1	1
	0.8	4	5	4	3	2	2
	0.6	5	7	12	6	6	6
	0.4	8	8	16	20	9	17
	0.3	10	19	16	23	19	20
	0.2	29	27	41	40	34	28
Fresh Water	1.0	3	4	3	1	1	1
	0.8	4	4	4	2	2	2
	0.6	7	7	6	4	3	3
	0.4	7	7	6	6	5	5
	0.3	14	13	13	14	6	6
	0.2	28	27	23	20	15	15

Figure 5 Relationship between the δ_7 Strength of Digested Sludge and C/S (Water Content 96%)

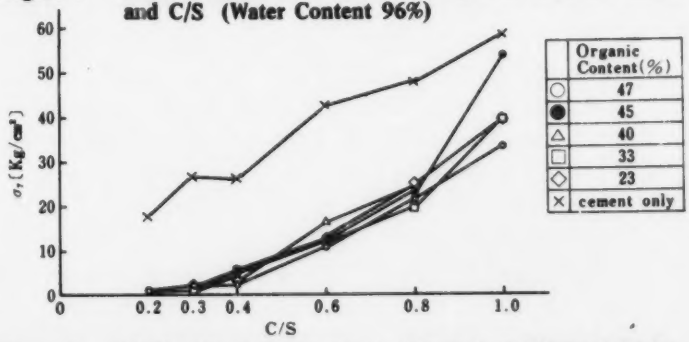


Figure 6 Relationship between the δ_7 Strength of Digested Sludge and Organic Matter (Water Content 96%)

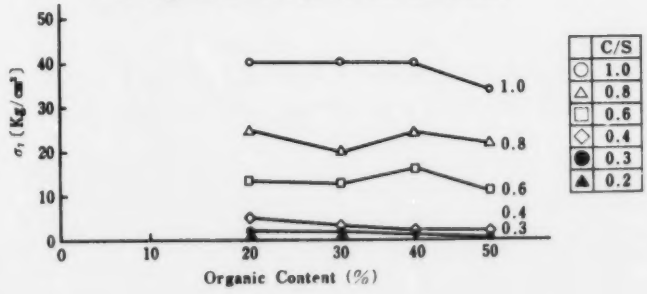


Figure 7 Relationship between the C/S of Digested Sludge and δ_{28} Strength (Water Content 96%)

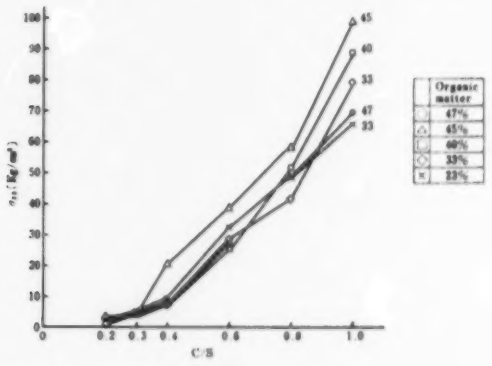


Figure 8 Relationship between the Organic Matter Content and the δ_{28} Strength (Water Content 96%)

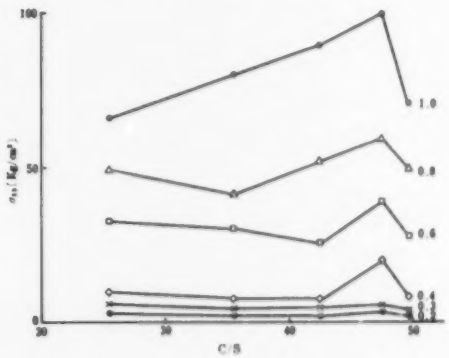


Figure 9 Relationship between the C/S of Digested Sludge and δ_{28} Strength Organic Content (%)

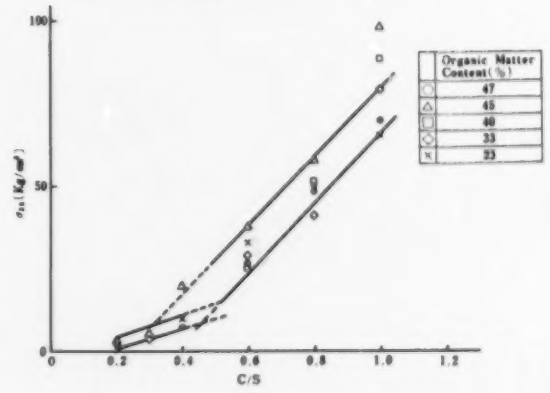


Figure 10 Relationship between the δ_7 Strength of Digested Sludge and C/S (Organic Content 47%)

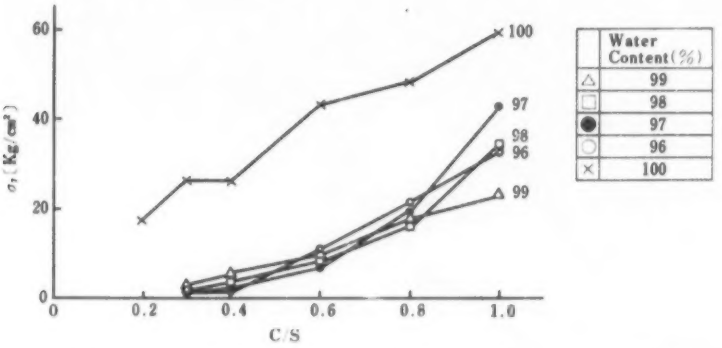


Figure 11 Relationship between the δ_7 of Digested Sludge and the Water Content (Organic Content 47%)

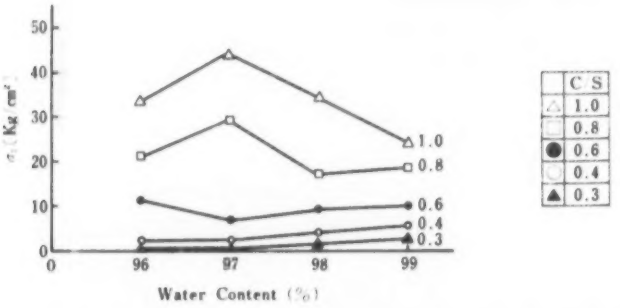
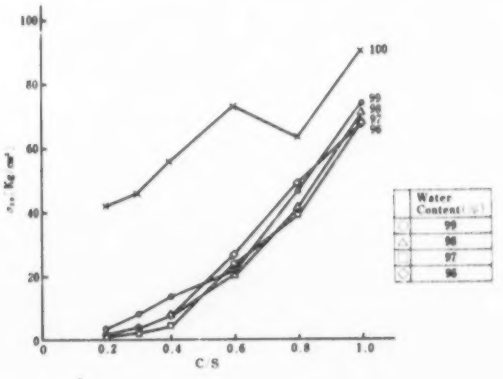


Figure 12 Relationship between the C/S of Digested Sludge and δ_{28} (Organic Content 47%)



Figures 10 and 11 show the relationship between σ_7, C/S and water content in samples with 97, 98 and 99% water content prepared by adding tap water to digested sludge which had a water content of 96% and 47% organic substances.

Figures 12 and 13 show the relationship between σ_{28}, C/S and water content. The influence of water content is negligible in relation to strength when it is in the 96–99% range if the C/S ratio is constant.

In finding the relationship between C/S and σ_{28} from **Figure 14**, C/S = 0.5 is taken as the limit and the following relationships found:

C/S	Water content (%)		
0.2 – 0.5	98 – 99	$\sigma_{28} = -4 + 35C/S$	(14)
	96 – 96	$\sigma_{28} = -2 + 16C/S$	(15)
0.5 – 1.0	96 – 99	$\sigma_{28} = -C + 115C/S$ (C=36–42).	(16)

Figure 13 Relationship between the Water Content of Digested Sludge and δ_{28} (Organic Content 47%)

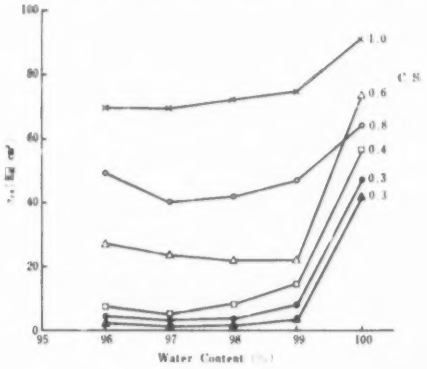


Figure 14 Relationship between δ_{28} of Digested Sludge and C/S (Organic Content 47%)

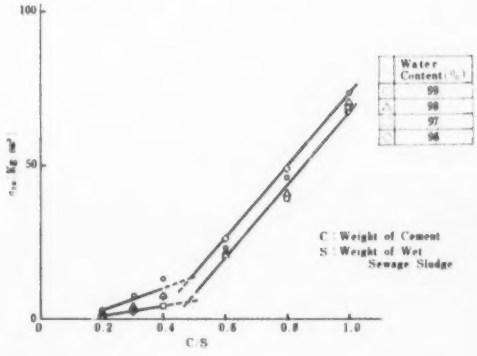


Figure 15 shows the minimum amount of cement per unit of solidified material for σ_7. As in the case of raw sludge, the minimum amount of cement required, when water content of the sludge was in the 92–96% range, was 5–7.5 kg per 1 kg of dried sludge.

2. Solidified Sludge Leaching Test

In solidifying sludge, not only the strength of the finished product but also the checking of the leaching of heavy metals from it must be taken into consideration.

Leaching tests were carried out with dredged mud and sludge from drains using only what was considered to be sufficient cement to assure solidification.

(1) Test Method

Three blocks (measuring 4 cm x 4 cm x 16 cm each) of solidified dredge and drain sludge were soaked in 4.5 liters of sea and fresh water and the water was changed at 7, 28, and 56 days after soaking was begun and in each case the concentrated of heavy metals measured. Water temperature was maintained at 20°C throughout the test period.

(2) Results

1) Cement block leaching test

As a solidification blank test, quick-hardening Portland cement was used. **Table 2** shows the heavy metals in the cement used in the solidification test. Solidification was carried out with this cement and three 4 cm x 4 cm x 16 cm blocks were soaked in 4.5 liters of water. The results are shown in **Table 3**.

Figure 15 MInimum C/S dry necessary for Unit Solid of Digested Sludge (7-day Strength) (Organic Content 47%)

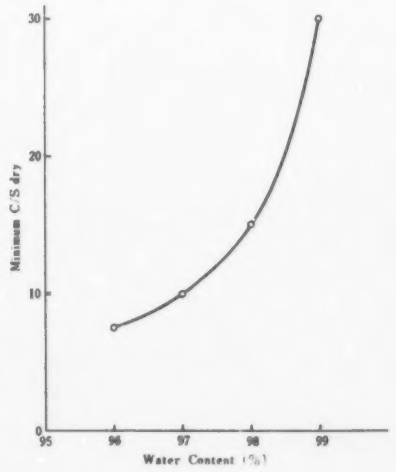


Table 2 Heavy Metal Contents in Cement (μg/g)

Sample	Cd	Pb	As	Cr	Cu	Zn	Note
A	0.9	60	28	190	125	959	Portland cement
B	2.3	99	56	51	94	570	Quick Portland cement
C	0.9	135	9	42	179	1,490	Quick Portland cement

Table 3 Cement Blank Test

Curing days	Proposition			Curing water (mℓ)	Compressive strength (kg/cm2)	Concentration in Exuded Liquid (ppm)						
	C/W	C (g)	Winj (g)			Cynide	Total Hg	Organic P	Cd	Total Cr	As	Pb
7	0.4	360	900	1500	29	0.00	0.00	0.00	0.00	0.06	0.00	0.02
28	0.4	360	900	1500	63	–	0.00	0.00	0.00	0.04	0.00	0.01
56	0.4	360	900	1500	84	0.00	0.00	0.00	0.00	0.06	0.00	0.00

Note: C: Cement Winj: Water Injected

Table 4 Concentration of Heavy Metals and Cynide in Dredged Sludge

Sample	Concentration (dry base, μg/g)								Water content (%)
	Cynide	Alkyl Hg	Total Hg	Organic P	Cd	Total Cr	As	Pb	
TS– 1	0.0	0.00	1.87	0.4	2.4	178	8.7	46.2	39.07
TS– 3	0.0	0.00	0.36	0.2	0.6	16	4.7	23.4	66.10
TS– 4	0.0	0.00	0.72	0.4	1.6	142	12.2	65.2	45.89
TS– 7	0.0	0.00	2.36	0.1	2.8	112	11.8	120	58.03
TS– 8	0.0	0.00	0.34	0.0	0.4	110	7.3	17.9	51.21
TS–10	0.0	0.00	1.68	0.3	2.2	109	12.8	114	53.45
TS–13	0.0	0.00	1.43	0.9	5.6	224	1.8	105	81.03
TS–14	0.0	0.00	0.33	0.1	1.2	136	5.9	25.6	55.14
TS–15	0.0	0.00	0.50	0.0	0.4	123	4.8	12.9	44.57
TS–17	0.0	0.00	0.40	0.4	3.8	142	4.5	26.9	74.05

2) Dredged mud block leaching test

4 cm x 4 cm x 16 cm test blocks cured and solidified for four days in a constant temperature (20°C) and constant humidity room were tested for leaching in the manner described in the Test Method section, (1) above. **Figure 16** shows the sample collection stations and **Table 4** heavy metal content, while **Table 5** records leaching test results.

3) Sewage sludge block leaching test

4 cm x 4 cm x 16 cm test blocks cured and solidified for four days in a constant temperature, constant humidity room were leaching tested in the manner described in the Test Method section, (1) above. **Table 6** shows heavy metal content and **Tables 7** and **8** the leaching test results.

(3) Discussion

1) No leaching of heavy metals was observed in the case of the dredged mud blocks but chromium leached out of some of the drain sludge blocks. This was solidified ash from the Sunamachi (SA) and Odai (OA) sewage treat plants reported previously.[1] As **Tables 6** and **9** show, this difference was apparently not due to the influence of compression strength but, as shown in **Table 6**, to the difference in chromium concentrations in the blocks. According to test results obtained by Terashima and Iwai, leaching varies according to the type of metal. For example, the diffusion of ^{90}Sr and ^{137}Cs within the solidified cement blocks is dominant; this depending on porosity, etc., while ^{60}Co combines well with cement hydrate and it is reported[3] that surface resolution and dissolution attributable to flaking is the dominant tendency. In this present series of tests, while it was not possible to elucidate the mechanism of elusion in leaching tests involving chromium, etc., excepting for SA, there was hardly any elusion noted at all with either dredged mud or sewage sludge. It still remains necessary therefore both to clarify the mechanism involved in leaching and to work out an effective composition scheme to prevent exudation.

2) When cement slurry containing sewage sludge was placed directly in water, the elusion of heavy metals occurred due to exuding of water as the concrete compacts and hardens (also called "bleeding").

Figure 17 shows the relationship between water content and C/Co when C/S = 0.2 (C is Cd and Pb concentration in the exuded liquid and Co is Cd and Pb concentration in the block when raw sludge from Ukima Sewage Treatment Plant was used (organic matter content was 52.5%)). This figure shows the contents of the exuded liquid after 28-day curing. As the water content of the sludge increases,

Figure 16 Samping Spots of Dredged Mud

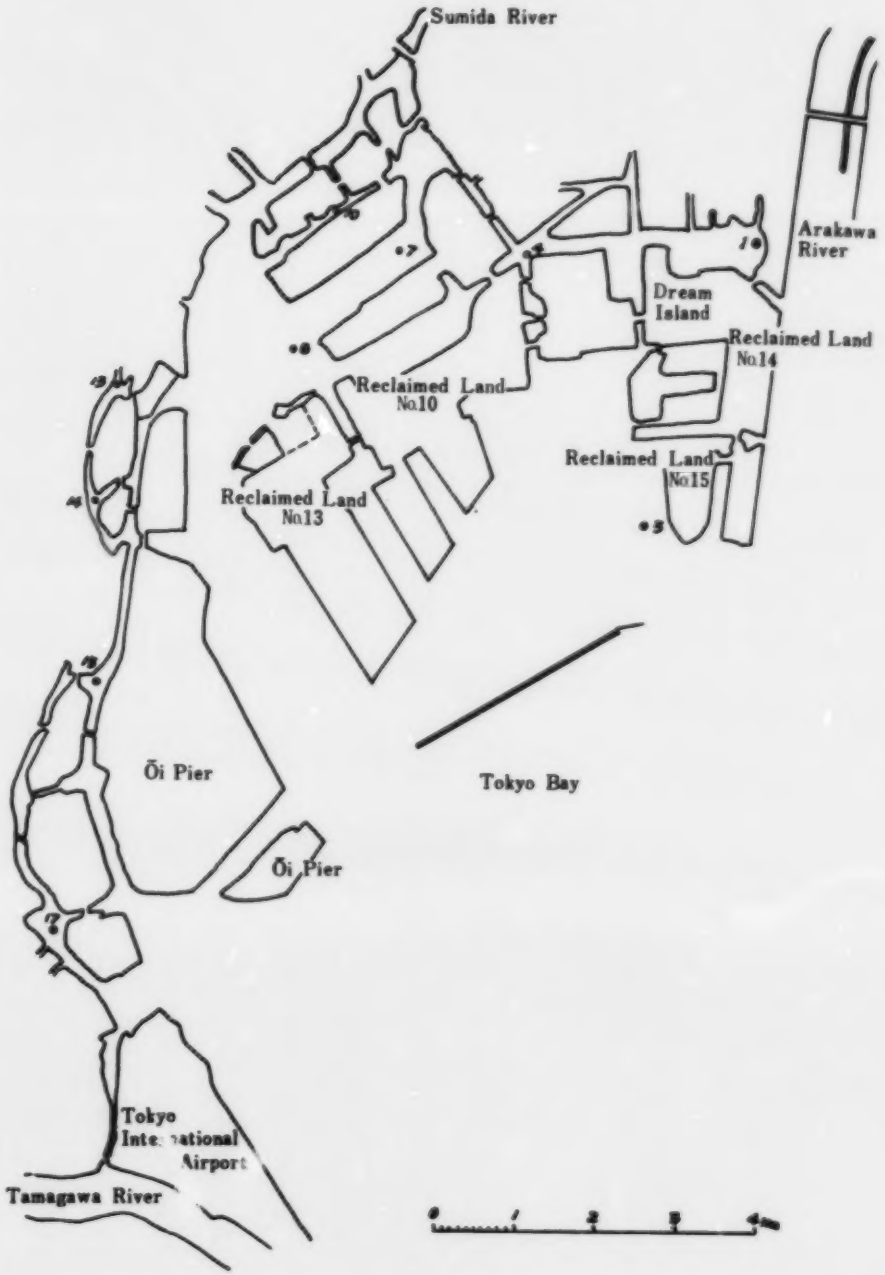


Table 5 Result of Leaching Test of Dredged Sludge

Water temperature 20°C

Sample	Proportion (weight ratio) Swet : Wmj : C	Age (day) during curing period	Curing days	Curing water	Concentration of heavy metals and cyanide in curing water (ppm) Cyanide	Alkyl Hg	Total Hg	Organic P	Cd	Total Cr	As	Pb
TS– 1	5 : 0 : 2	4～11	7	Fresh	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	11～32	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	32～60	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	4～11	7	Sea	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	11～32	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	32～60	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
TS– 3	5 : 0 : 2	4～11	7	Fresh	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	11～32	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	32～60	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	4～11	7	Sea	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	11～32	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	32～60	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
TS– 4	5 : 0 : 2	4～11	7	Fresh	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	11～32	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	32～60	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	4～11	7	Sea	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	11～32	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	32～60	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
TS– 7	5 : 0 : 2	4～11	7	Fresh	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	11～32	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	32～60	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	4～11	7	Sea	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	11～32	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	32～60	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
TS– 8	5 : 0 : 2	4～11	7	Fresh	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	11～32	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	32～60	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	4～11	7	Sea	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	11～32	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	32～60	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
TS–10	5 : 0 : 2	4～11	7	Fresh	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	11～32	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	32～60	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	4～11	7	Sea	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	11～32	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	32～60	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
TS–13	5 : 0 : 2	4～11	7	Fresh	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	11～32	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	32～60	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	4～11	7	Sea	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	11～32	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	32～60	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
TS–14	5 : 0 : 2	4～11	7	Fresh	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	11～32	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	32～60	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	4～11	7	Sea	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	11～32	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	32～60	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
TS–15	5 : 0 : 2	4～11	7	Fresh	0.0	0.000	0.000	0.00	0.00	0.1	0.00	0.0
	5 : 0 : 2	11～32	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	32～60	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	4～11	7	Sea	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	11～32	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	32～60	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
TS–17	5 : 0 : 2	4～11	7	Fresh	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	11～32	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	32～60	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	4～11	7	Sea	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	11～32	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	32～60	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0

Note: Swet : Wet sample

For the all such tests in this report was used curing water, both fresh and sea, in which no such heavy metals or cyanide were detected.

Table 6 Result of Research at Some Sewage Treatment Plants

Unit: μg/Swet 1g

Item / Sample	Cynide	Alkyl Hg	Total Hg	Organic P	Cd	Total Cr	As	Pb	Water content (%)
O·R·S	0.0			0.3	3.30	114	1.7	38.7	
O·D·S	0.0			0.2	1.90	75.7	0.6	24.7	
O·Dw·S	0.6			0.3	1.63	55.4	0.5	34.2	
O·D·C	10.2		12.2	1.6	13.8	379	4.8	186	72.1
O·Sp·L	0.1			0.0	0.10	2.2	0.0	0.9	
O·Fi	0.1			0.0	0.00	0.0	0.0	0.0	
O·A	0.4	0.00	0.03	0.4	20.9	1664	19.1	782	4.7
ORHSpL	0.0			0.0	0.0	3.5	0.2	0.1	
O·R·H·Fi	0.0			0.0	0.1	3.5	0.3	0.2	
O·R·H·C	0.0		14.1	2.4	18.6	566	6.0	222	68.0
O·R·C·Fi	0.0			0.0	0.00	0.3	0.0	0.1	
O·R·C·C	12.9		9.00	2.5	8.80	274	4.1	110	79.5
O·R·F·Fi	0.0			0.0	0.01	0.5	0.0	0.5	
O·R·F·C	0.0		11.5	2.3	14.0	682	4.7	1116	76.2
U·R·S	1.2			0.2	6.70	374	0.3	861	
U·R·Dw·S	7.9			0.1	2.70	164	0.3	395	
U·R·C	29.3	0.00	0.74	0.7	22.7	1205	1.7	3660	74.5
U·R·F	0.5			0.0	0.20	13.9	0.0	31.0	
Agent for vacuum filtration $FeCl_3$ (38%)	0.0			0.0	0.00	381	0.0	17.1	
URHSpL	0.0			0.0	0.01	6.80	0.2	1.0	
U·R·H·Fi	0.0			0.0	0.10	11.4	0.1	14.0	
U·R·H·C	2.8		0.80	1.2	44.3	2738	4.0	7029	66.9
U·R·C·Fi	0.4			0.0	0.02	1.00	0.1	3.3	
U·R·C·C	54.2		0.90	1.0	24.3	1316	2.6	3435	75.7
U·R·F·Fi	0.1			0.0	0.03	1.20	0.1	4.8	
U·R·F·C	13.6		1.30	1.0	32.3	2045	3.7	4950	72.5
S·R·S	0.0			0.3	1.00	194	2.4	24.9	
S·D·S	0.0			0.3	4.30	180	1.7	28.0	
S·R·C	8.9	0.00	1.02	2.7	6.10	771	9.0	148	76.3
S·D·C	0.5		1.12	1.3	7.40	989	8.5	17.3	74.9
S·R·Dw·S	0.7			0.2	0.60	79.7	1.1	15.6	
S·D·Dw·S	0.1			0.2	10.5	184	1.4	21.1	
S·R·Sp·L	0.0			0.1	0.30	19.6	0.2	4.5	
S·R, S·D } Fi	0.2			0.0	0.00	0.3	0.0	0.1	
S·A	1.4	0.00	0.03	0.4	9.30	4096	49.6	294	0.80
Agent for vacuum filtration $Ca(OH)_2$	0.0	0.00	0.03	0.0	1.00	12.0	0.4	4.1	0.49
S·R·H·SpL	0.0			0.0	0.03	5.30	0.3	0.9	
S·R·H·Fi	0.0			0.0	0.01	4.10	0.3	0.3	
S·R·H·C	0.0		2.06	1.3	13.0	2509	24.0	374	70.1
S·DHSpL	0.0			0.0	0.01	3.70	0.3	0.2	
S·D·H·Fi	0.0			0.0	0.05	8.50	0.2	1.1	
S·D·H·C	0.0		2.46	1.4	13.0	2316	16.8	337	73.5
S·R·C·Fi	0.1			0.0	0.00	0.60	0.0	1.2	
S·R·C·C	0.0		0.73	1.5	5.00	94.5	22.3	134	81.6
S·D·C·Fi	0.1			0.0	0.01	1.60	0.0	0.4	
S·D·C·C	0.5		0.94	0.7	6.70	1115	13.2	166	8.0
S·R·F·Fi	0.0			0.0	0.00	0.70	0.0	0.2	
S·R·F·C	0.0		1.65	2.1	6.80	1304	16.1	198	78.2
S·D·F·Fi	0.1			0.0	0.01	2.00	0.0	0.4	
S·D·F·C	0.0		1.31	0.6	25.5	1561	7.0	2402	81.7

Table 7 Result of Leaching Test of Sewage Sludge (1)

Water temperature 20°C

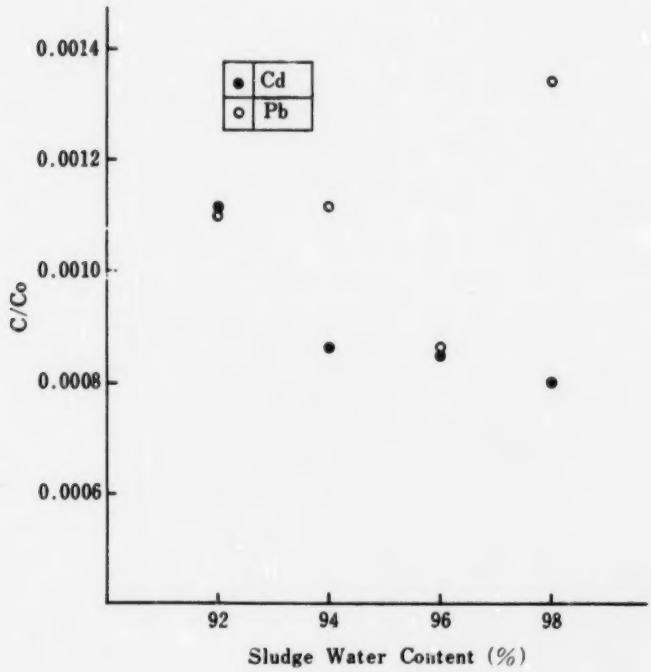
Sample	Proposition (weight ratio) Swet : Winj : C	Age (day) during curing period	Curing days	Curing water	Concentration of heavy metals and cynide in curing water (ppm)							
					Cynide	Alkyl Hg	Total Hg	OrganicP	Cd	Total Cr	As	Pb
SRS–1	5 : 0 : 2	7～14	7	Fresh	0.0	0.000	0.001	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	14～35	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	35～63	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	7～14	7	Sea	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	14～35	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	35～63	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
ORS–1	5 : 0 : 2	7～14	7	Fresh	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	14～35	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	35～63	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	7～14	7	Sea	0.0	0.000	0.000	0.00	0.00	0.1	0.00	0.0
	5 : 0 : 2	14～35	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	35～63	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
URS–1	5 : 0 : 2	12～19	7	Fresh	0.0	0.000	0.003	0.00	0.00	0.0	0.00	0.2
	5 : 0 : 2	19～40	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.2
	5 : 0 : 2	40～68	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.1
	5 : 0 : 2	12～19	7	Sea	0.0	0.000	0.000	0.00	0.00	0.2	0.00	0.0
	5 : 0 : 2	19～40	21		0.0	0.000	0.000	0.00	0.00	0.1	0.00	0.0
	5 : 0 : 2	40～68	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
URS–2	5 : 0 : 2	7～14	7	Fresh	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.3
	5 : 0 : 2	14～35	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.2
	5 : 0 : 2	35～63	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	7～14	7	Sea	0.0	0.000	0.000	0.00	0.00	0.1	0.00	0.1
	5 : 0 : 2	14～35	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	35～63	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
SRS–3	5 : 0 : 2	7～14	7	Fresh	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	14～35	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	35～63	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	7～14	7	Sea	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	14～35	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	35～63	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
SDS–1	5 : 0 : 2	7～14	7	Fresh	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	14～35	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	35～63	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	7～14	7	Sea	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	14～35	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	35～63	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
SDS–3	5 : 0 : 2	7～14	7	Fresh	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	14～35	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	35～63	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	7～14	7	Sea	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	14～35	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	35～63	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
ODS–1	5 : 0 : 2	7～14	7	Fresh	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	14～35	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	35～63	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	7～14	7	Sea	0.0	0.000	0.000	0.00	0.00	0.1	0.00	0.0
	5 : 0 : 2	14～35	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	5 : 0 : 2	35～63	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
SRC–1	4 : 1 : 2	7～14	7	Fresh	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	4 : 1 : 2	14～35	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	4 : 1 : 2	35～63	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	4 : 1 : 2	7～14	7	Sea	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	4 : 1 : 2	14～35	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	4 : 1 : 2	35～63	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0

Table 8 Result of Leaching Test of Sewage Sludge (2)

Water temperature 20°C

Sample	Proposition (weight ratio) Swet : Wint : C	Age (day) during curing period	Curing days	Curing water	Concentration of heavy metals and cyanide in curing water (ppm)							
					Cyanide	Alkyl Hg	Total Hg	Organic P	Cd	Total Cr	As	Pb
URC-1	4 : 1 : 2	7～14	7	Fresh	0.1	0.000	0.001	0.00	0.00	0.0	0.00	0.4
	4 : 1 : 2	14～35	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.1
	4 : 1 : 2	35～63	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	4 : 1 : 2	7～14	7	Sea	0.1	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	4 : 1 : 2	14～35	21		0.1	0.000	0.000	0.00	0.00	0.0	0.00	0.1
	4 : 1 : 2	35～63	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
SDC-1	4 : 1 : 2	7～14	7	Fresh	0.0	0.000	0.001	0.00	0.00	0.0	0.00	0.0
	4 : 1 : 2	14～35	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	4 : 1 : 2	35～63	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	4 : 1 : 2	7～14	7	Sea	0.0	0.000	0.001	0.00	0.00	0.0	0.00	0.0
	4 : 1 : 2	14～35	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	4 : 1 : 2	35～63	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
ODC-1	4 : 1 : 2	7～14	7	Fresh	0.0	0.000	0.001	0.00	0.00	0.0	0.00	0.0
	4 : 1 : 2	14～35	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	4 : 1 : 2	35～63	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	4 : 1 : 2	7～14	7	Sea	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	4 : 1 : 2	14～35	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	4 : 1 : 2	35～63	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
SA-1	10 : 8 : 1	1～8	7	Fresh	0.0	0.000	0.000	0.00	0.00	0.2	0.00	0.0
	10 : 8 : 1	8～29	21		0.0	0.000	0.000	0.00	0.00	0.1	0.00	0.0
	10 : 8 : 1	29～57	28		0.0	0.000	0.000	0.00	0.00	0.1	0.00	0.0
	10 : 8 : 1	1～8	7	Sea	0.1	0.000	0.000	0.00	0.00	1.9	0.00	0.0
	10 : 8 : 1	8～29	21		0.1	0.000	0.000	0.00	0.00	1.1	0.00	0.0
	10 : 8 : 1	29～57	28		0.0	0.000	0.000	0.00	0.00	0.4	0.00	0.0
SA-2	10 : 8 : 1	1～8	7	Fresh	0.0	0.000	0.000	0.00	0.00	0.2	0.00	0.0
	10 : 8 : 1	8～29	21		0.0	0.000	0.000	0.00	0.00	0.1	0.00	0.0
	10 : 8 : 1	29～57	28		0.0	0.000	0.000	0.00	0.00	0.1	0.00	0.0
	10 : 8 : 1	1～8	7	Sea	0.1	0.000	0.000	0.00	0.00	1.8	0.00	0.0
	10 : 8 : 1	8～29	21		0.1	0.000	0.000	0.00	0.00	0.9	0.00	0.0
	10 : 8 : 1	29～57	28		0.0	0.000	0.000	0.00	0.00	0.3	0.00	0.0
SA-3	10 : 8 : 1	1～8	7	Fresh	0.0	0.000	0.000	0.00	0.00	0.3	0.00	0.0
	10 : 8 : 1	8～29	21		0.0	0.000	0.000	0.00	0.00	0.2	0.00	0.0
	10 : 8 : 1	29～57	28		0.0	0.000	0.000	0.00	0.00	0.1	0.00	0.0
	10 : 8 : 1	1～8	7	Sea	0.1	0.000	0.000	0.00	0.00	1.4	0.00	0.0
	10 : 8 : 1	8～29	21		0.0	0.000	0.000	0.00	0.00	0.4	0.00	0.0
	10 : 8 : 1	29～57	28		0.0	0.000	0.000	0.00	0.00	0.1	0.00	0.0
OA-1	10 : 8 : 1	1～8	7	Fresh	0.0	0.000	0.000	0.00	0.00	0.1	0.00	0.0
	10 : 8 : 1	8～29	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	10 : 8 : 1	29～57	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	10 : 8 : 1	1～8	7	Sea	0.0	0.000	0.000	0.00	0.00	0.1	0.00	0.0
	10 : 8 : 1	8～29	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	10 : 8 : 1	29～57	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
OA-2	10 : 8 : 1	1～8	7	Fresh	0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	10 : 8 : 1	8～29	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	10 : 8 : 1	29～57	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	10 : 8 : 1	1～8	7	Sea	0.0	0.000	0.000	0.00	0.00	0.1	0.00	0.0
	10 : 8 : 1	8～29	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	10 : 8 : 1	29～57	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
OA-3	10 : 8 : 1	1～8	7	Fresh	0.0	0.000	0.000	0.00	0.00	0.1	0.00	0.0
	10 : 8 : 1	8～29	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	10 : 8 : 1	29～57	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	10 : 8 : 1	1～8	7	Sea	0.0	0.000	0.000	0.00	0.00	0.2	0.00	0.0
	10 : 8 : 1	8～29	21		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0
	10 : 8 : 1	29～57	28		0.0	0.000	0.000	0.00	0.00	0.0	0.00	0.0

Figure 17 Relationship between the concentration of Cd and Pb in Breeding Water and Sludge Water Content



there is a tendency for C/Co to decrease a little, and when the water content of the sludge is high, block density is low (compared with 92%, in the case of 98%, about a third). It is felt that these factors affect the results considerably.

3. Conclusion

(1) The minimum quantity of cement necessary to carry out solidification is 5–7.5 kg per 1 kg of dried sludge.

(2) While the amount of organic substances in sludge is taken as a factor in determining the strength of the block when this sludge is solidified with cement, strength is, however, primarily determined by the C/S ratio.

(3) Heavy metals were seen to be exuded from the SA sludge and cement blocks among the various types of sludge samples. SA has more heavy metals in it than other sludge and, even when compared with OA to which it is considered to have similar properties, quite a difference is seen. It would seem that this is affected by the block-soaking solution density gradient.

Table 9 Propositions and the Test Results

*Sea water curing

No.	Sample	Water content of sample (%)	Proposition A (g)	C (g)	Winj (g)	C/A	Winj/C + A	Flow valve (mm)	Concreted volume (Kg/m³)	Weight per volume after hardening (Kg/m³) age 7 days	age 14 days	age 28 days	age 70 days	Compressive strength (Kg/cm²) age 7 days	age 14 days	age 28 days	age 70 days
1	OA-1	1.49	2000	200	1599	0.10	0.727	999	1600	1580	1590	1610	1600 1620*	22	29	36	42 36*
2	OA-2	0.48	2000	200	1599	0.10	0.727	192	1600	1590	1590	1620	1600 1610*	27	31	33	35 48*
3	OA-3	6.47	1900	190	1519	0.10	0.727	280	1540	1540	1560	1570	1580 1580*	6	9	11	13 21*
4	SA-1	0.68	2200	220	1759	0.10	0.727	281	1490	1530	1540	1570	1550 1560*	11	17	21	27 28*
5	SA-2	2.22	2000	200	1599	0.10	0.727	liquid	1520	1610	1580	1580	1580 1620*	6	10	13	24 25*
6	SA-3	0.11	2000	200	1599	0.10	0.727	284	1540	1530	1550	1580	1610 1600*	11	17	21	33 35*

Note: A: Ash

(4) When cement slurry containing sludge was placed directly in water, the exudation of heavy metals occurs due to "bleeding", etc., the amounts in the block being about 1/1000 part.

References:

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2) JIS A1203 (1950)
3) Y. Terashima., et al., "ON THE MECHANISM OF LEACHING OF ^{137}Cs, ^{90}Sr, AND ^{60}Co FROM THE SOLIDIFIED WITH CEMENT" Proceedings of JSCE. 51, No.201 (1972)